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Partial Defect Testing of Pressurized Water Reactor Spent Fuel Assemblies

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ABSTRACT

In our earlier papers we have reported a development of a novel technology to detect diversion of spent fuel from pressurized water reactor (PWR) spent fuel assemblies. The concept of spent fuel partial detection technology lies in the effective evaluation of thermal neutron and gamma signals measured inside guide tube holes of the PWR spent fuel assemblies. One of the key features of the data evaluation method is the concept of the base signature obtained by normalizing the ratio of gamma to neutron signals at each measurement position. As the base signature is relatively invariant to the characteristic variations of spent fuel assemblies such as initial fuel enrichment, cooling time, and burn-up, the methodology can be an extremely powerful tool that does not require operator declared data and can be used without moving the fuel from the storage rack in the pool. For the hypothetical case of a symmetric diversion, separate analysis can be applied using already available individual normalized gamma or neutron signature profiles. In this paper we report results from an experimental campaign conducted on PWR spent fuel assemblies which cover Westinghouse type 14x14, 16x16 and 17x17 fuel product lines, and their analysis. The experiments demonstrated the validity of the verification methodology. Thus, the envisaged PDET system would be a new powerful safeguards tool which does not require any operator provided data and that can potentially detect as low as 10% missing pins in an in-situ condition.

INTRODUCTION

Possible diversion of fuel pins from spent fuel assembly, known as pin diversion or partial defect, has been an issue over a few decades in safeguards community as replacement of damaged spent fuel pins with stainless steel pins is an accepted process in nuclear industry. According to the present safeguards criteria, a partial defect test should be able to detect 50% of missing fuel rods (pins) or replaced with dummy fuel rods from light water reactor spent fuel assemblies. The Standing Advisory Group on Safeguards Implementation (SAGSI) recognized this problem and encouraged Member State Support Program to advance appropriate technologies for detecting pin diversion [1]. A study to tackle this partial defect testing has been carried out by three countries as a joint member state support program (MSSP) project. It concluded that the fork measurements even with enhanced fork detector cannot be applied for partial defect test without use of the nuclear facility operator declared data [2]. To date, there is no instrument that has the capability of performing partial defect testing.

Development of a novel safeguards verification method at Lawrence Livermore National Laboratory to address partial defect verification of spent fuel assemblies has been in progress for last several years [3-8]. The novel methodology uses thermal neutron and gamma information obtained by tiny neutron and gamma detectors inside guide tubes of PWR spent fuel assemblies. The data obtained in such a manner provide spatial distribution of neutron and gamma flux within a spent fuel assembly, thus creating unique profiles when the data are plotted against detector positions. In particular, the ratio of the gamma signal to the thermal neutron signal at each detector location normalized to the peak ratio of all the detector locations gives a unique signature, known as base signature profile, that is sensitive to missing pins, but shows little sensitivity to enrichment variations, cooling times or burn-ups.

This paper reports results from an experimental campaign conducted on PWR spent fuel assemblies which cover Westinghouse type 14x14, 16x16 and 17x17 fuel product lines, and their analysis. Accompanying paper expands the simulation and analysis of the 16x16 or 17x17 assemblies.

EXPERIMENTS

Description of the PWR Spent Fuel Assemblies

Shown in Table 1 is the basic information of the spent fuel assemblies used for experiments. These were discharged from an actual commercial PWR nuclear power plant and being stored with the top nozzle removed. Figures 1 and 2 show fuel rod arrangement along with positions of the missing rods. Although all fuel rods were present at the time of discharge, since then many fuel rods have been removed for destructive testing. The positions where the fuel rods were removed were shown in red and were filled with water. The assembly J14 had only one fuel rod missing and essentially represented a full assembly.

Table 1: Description of the three PWR spent fuel assemblies used for experiments.

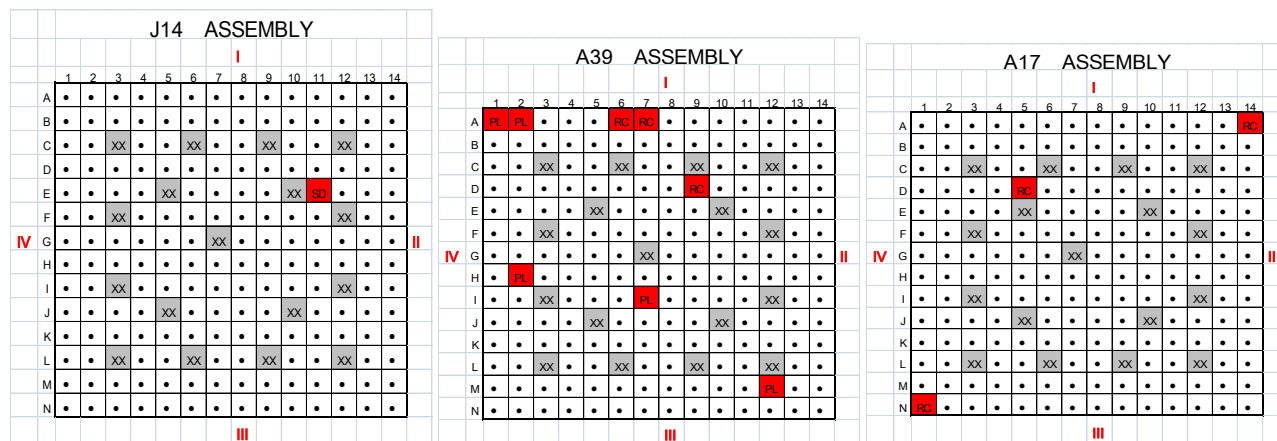| Fuel ID	Fuel Type	Burnup (GWd/tU)	Discharge Date	Initial Enr. (%)	Number of guide tubes	Number of missing rods
J14	WH 14x14	37.5	1/20/89	3.2	16	1 (0.6%)
A39	WH 14x14	25.3	1/30/81	2.12	16	8 (4.5%)
A17	WH 14x14	17.1	10/27/79	2.12	16	3 (1.7%)
J44	16x16	35.0	5/29/92	3.49	20	22 (9.4%)
K23	17x17	52.0	?	?	24	16 (6.1 %)

Figure 1: The diagram of fuel rod arrangement of Westinghouse type 14x14 PWR spent fuel assemblies on which measurements were performed (ID: J14, A39, A17). Red color indicates positions where rods were removed and left filled with water. XX indicates guide tube location where measurements were made.
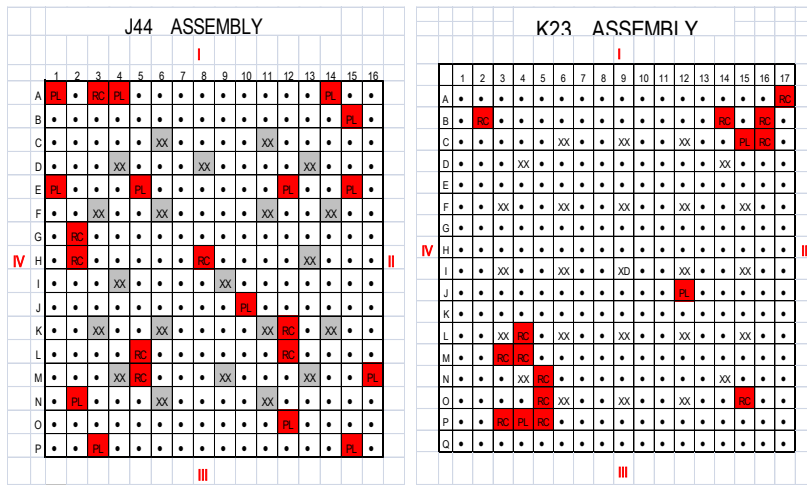
Figure 2: The diagram of fuel rod arrangement of 17x17 (K23) and 16x16 (J44) PWR spent fuel assemblies on which measurements were performed. Red color indicates positions where rods were removed and left filled with water. XX indicates guide tube location where measurements were made.

Neutron Measurements

An in-house developed underwater neutron measurement system was used to measure neutron signals inside guide tubes in PWR spent fuel assemblies. The system consisted of a tiny Centronic fission chamber (6.3 mm diameter) which was placed inside a 1.5 meter long water proof stainless steel tube and a larger cylinder which contained PDT preamplifier. The stainless steel tube was connected to the larger cylinder which would sit on the top of the spent fuel when the tube of the system was inserted into a guide tube of spent fuel assemblies. The system was designed to be used with MMCA (Mini Multi-Channel Analyzer), the standard IAEA MCA, and WinMCS, one of the standard pieces of software for neutron measurement at IAEA. At each measurement position, data were obtained in MCS mode with channel time of 30 seconds for 150 seconds. Overall it took only to obtain data at one measurement position.

Gamma Measurements

For gamma measurements, a special type of ion chamber was ordered and fabricated by Technical Associate. The ion chamber was waterproof and can be directly inserted into guide tubes. Whereas a computer and data acquisition software were need for thermal neutron measurements, gamma radiation dose could be directly read from a dose reader in a digital format (see Figure 4.) Dose rates were measured at every guide tube position for each assembly listed in the Table 1. It took only a few seconds for the reading to be stabilized.

Figure 3: A picture of neutron measurement system which uses a tiny fission chamber and PDT preamplifier.

Figure 4: A picture of gamma measurement system which uses an ion chamber: dose rate can be directly read from a dose reader.

RESULTS AND DISCUSSION

Figure 5 shows the neutron and gamma measurement results in terms of measured signature profiles for all Westinghouse 14x14 spent fuel assemblies, J14, A29 and A17. Measurements on J14, which has only one missing rod, produced signature profiles almost identical to the base signature profiles which should be symmetric and cyclic. Neutron and ratio profiles for A29 and A17 clearly deviated from base signature profiles although the amount of diversion was only a few percent. Gamma profiles showed relatively less deviation compared to the deviation caused by neutrons. The reason for this phenomenon is that the amount of gamma contribution to the measurement from pins, which lie behind the missing pins, increased as those gammas experience less attenuation through water which filled the location of missing pins.

Safeguards inspectors can use ratio profiles for PWR assembly verification, and gamma and neutron profiles for confirmatory verification. As an example for partial defect verification of J14, the ratio profile is first examined, then gamma and neutron. As all profiles show no deviation from the expected profile which should be symmetric and cyclic, no diversion can be assumed. However, if the profile shows deviation from the expected profile such as the ratio profile for A39 or A17, the inspector can easily conclude that A39 or A17 is disturbed without even having the detailed knowledge of the assemblies.

Figure 6 shows the neutron and gamma measurement results in terms of measured signature profiles for 16x16 and 17x17 spent fuel assemblies, J44 and K23. For the 16 x16 assembly, there were 22 missing rods which correspond to 9.4%, and for 17x17 assembly 6.1%. All signature profiles based on the measurement results for both J44 and K23 were neither cyclic nor symmetric, an indication of anomaly which would need further investigation if inspection based on this methodology was performed on these assemblies. Thus one can conclude again easily that there were anomalies on these assembly without requiring the detailed information on these assemblies from the facility operator.

The experiments demonstrated the validity of the verification methodology and the envisaged PDET system would be a new powerful safeguards tool which does not require movement of a spent fuel assembly for its partial defect verification or any operator provided data.
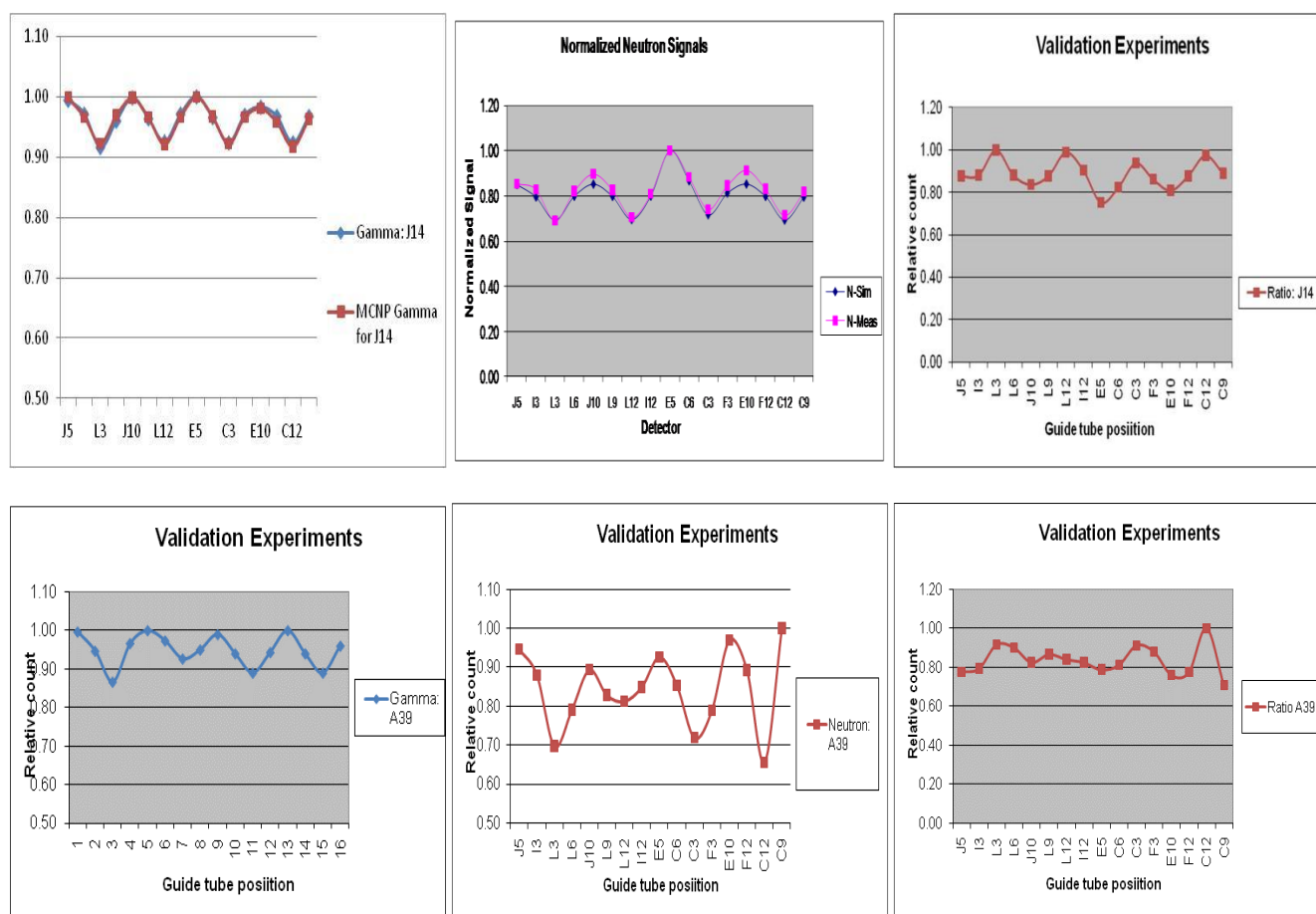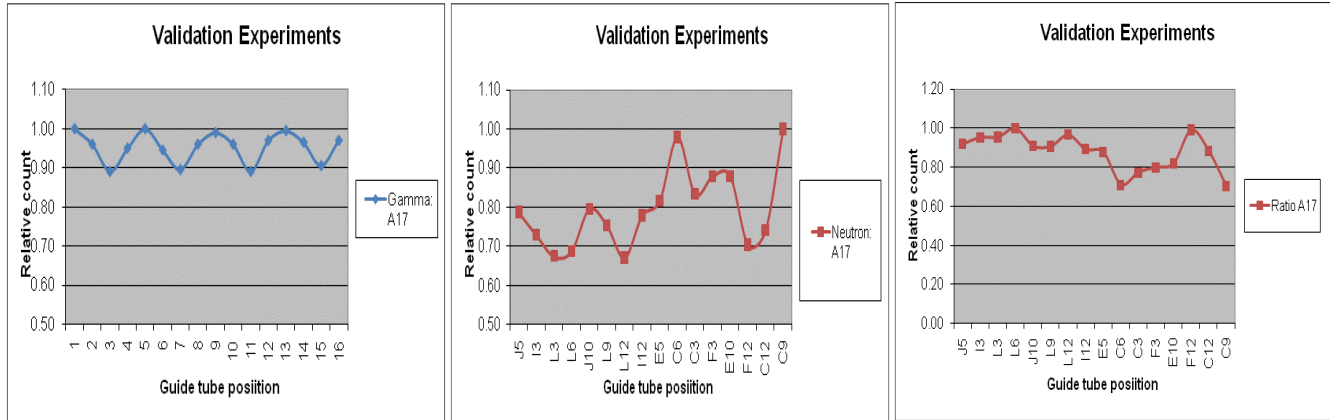
Figure 5: Measured signature profiles of gamma, neutron and the ratio for three 14x14 PWR spent fuel assemblies, J14, A39 and A17. Note that whereas the signature profiles of J14, which has only one missing rod, show almost no deviation from the base signature profiles, the other profiles clearly show deviation although the diversion was only a few percent.
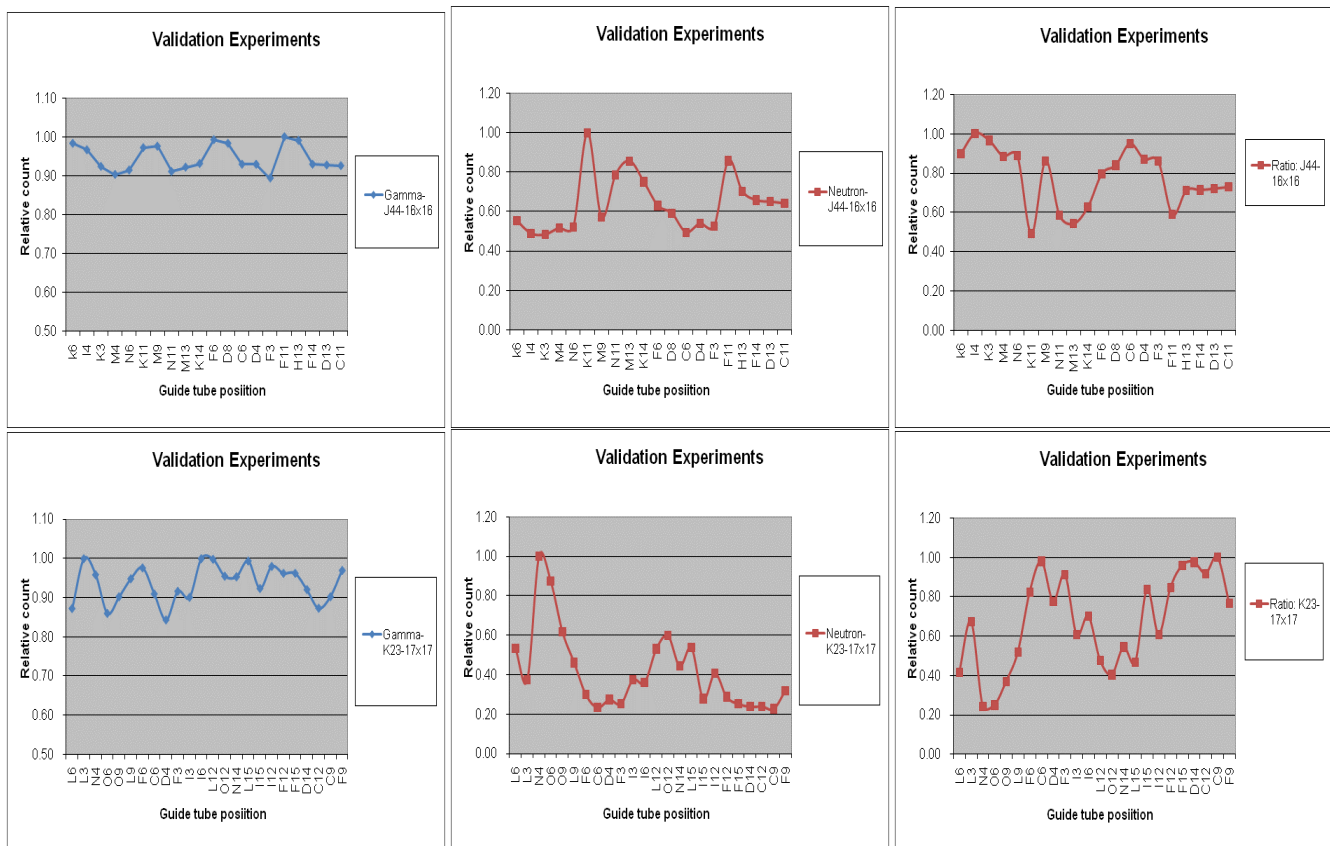

Figure 6: Measured signature profiles of gamma, neutron and the ratio for a 16x16 and 17x17 PWR spent fuel assemblies, J44 and K23. Note that measured signature profiles for both assemblies clearly show deviation. The percentages of missing rods were 9.4% and 6.1 % for J44 and K23 respectively.

CONCLUSION

Experiments with commercial PWR spent fuel assemblies have been performed to demonstrate that the pin diversion detection methodology can be used for partial defect verification of the PWR spent fuel assemblies without operator declared data. The results from the experiments demonstrate that not only the verification methodology is valid but also practical and easy to interpret data without extensive knowledge on spent fuel, a necessary feature for IAEA inspection activities. The methodology developed promises to be a powerful and practical way to detect partial defects that constitute 10% or more of the total active fuel pins. This far exceeds the detection threshold of 50% missing pins from a spent fuel assembly, a threshold defined by the IAEA Safeguards Criteria.

ACKNOWLEDGEMENT

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